

New facets of the pion-nucleon interaction experimental investigation
in the first and second resonance regions.

V.V.Sumachev,

Abstract.

The theoretical predictions for the non strange baryon resonance spectrum have the visible differences. This disagreement invites further experimental investigation of the pion-nucleon elastic interactions.

Recent experiments of the PNPI-ITEP collaborations resolved a part of the twofold ambiguities of the PWA. The PNPI-ITEP results were used in the new partial-wave analysis (PWA) FA02 of the George Washington University groups (2004 year).

The proposal for the additional spin-rotation parameters R and A measurements in the resonance region below 2.0 GeV is motivated. Such additional experiments are necessary to resolve possible remaining twofold ambiguities of the PWAs.

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1. Introduction.

Pion-nucleon interactions leading to the formation of nonstrange baryon resonance is one of fundamental interactions in the elementary particle physics.

Since the characteristics of baryon resonances (i.e. excited baryons) are extracted from the experimental πN data base using the procedure of a partial wave analysis (PWA), one of reasons of above mentioned disagreement may lie in an imperfection of the PWA procedure. A comparison of spectra of baryon resonances obtained on the base of three existing global PWAs performed by groups of Karlsruhe-Helsinki (KA84), Carnegie-Mellon/Berkeley (CMB) and Virginia Polytechnic Institute (VPI) show that these spectra differ rather essentially.

A closer inspection of this situation shows that the difference between results of three global PWAs is due to discrete ambiguities which are inherent to the PWA procedure. [D. Atkinson *et al.*](#) have shown that, in the inelastic region, unitarity is a rather weak constraint and there exist “islands of ambiguity” in the Argand diagrams of the partial waves.

The only kind of quantities which, having been measured, can remove discrete PWA ambiguities and help to choose the unique correct PWA solution are the spin rotation parameters A and R in πp elastic scattering. Just such measurements are scientific goals of the presented projects.

2. The new PWA and a problem of the “missing” resonances.

Numerous attempts to create a model that would exactly reproduce the baryon resonance spectrum that was presented in the RPP failed. The existing models usually predicted considerably more resonances (twice or more in number) than were found in elastic πN scattering. This problem is known as the problem of “missing” resonances.

The latest SP06 PWA that was made at George Washington University (2006) and included the modern experimental data appearing after 1980 revealed considerably fewer (approximately half) non strange baryon resonances than those presented in the RPP tables (2006) .

Tables 1 and 2 compare the results of the KA84, SM9 and FA02 PWAs with RPP 2002, 3P_0 -model and Skyrme model predictions.

You can see from Tables 1 and 2 that the FA02 PWA keeps only resonances that have the highest confidence status (****) in the RPP except for $D_{35}(1930)$ (which has the status ***).

Comparison of the PWA results and model predictions for the N^* - and Δ - resonances numbers is in the table 2a.

Table 1: Parameters of the N* - resonances.

PDG (2004)	L _{1,2J}	Status	KA84 (1984)	(³ P ₀)model (1994)	SM95 (1995)	FA02 (2004)	Skyrme (1985)
N(1440)	P ₁₁	****	1410(135)	1540	1467(440)	1468(360)	----
N(1520)	D ₁₃	****	1519(114)	1495	1515(106)	1516(98)	1715
N(1535)	S ₁₁	****	1526(120)	1460	1535(66)	1547(178)	1478
N(1650)	S ₁₁	****	1670(180)	1535	1667(90)	1651(130)	----
----	S ₁₁	----	----	----	1712(174)	----	----
N(1675)	D ₁₅	****	1679(120)	1630	1673(154)	1676(152)	1744
N(1680)	F ₁₅	****	1684(128)	1770	1678(126)	1683(134)	1823
N(1700)	D ₁₃	***	1731(110)	1625	----	----	----
N(1710)	P ₁₁	**	1723(120)	1770	[1770-i189]	----	1427
N(1720)	P ₁₃	****	1710(190)	1795	1820(354)	1750(256)	1982
N(1900)	P ₁₃	**	----	1870	----	----	----
----	P ₁₁	----	----	1880	----	----	----
----	P ₁₃	----	----	1910	----	----	----
----	P ₁₃	----	----	1950	----	----	----
----	P ₁₁	----	----	1975	----	----	----
----	F ₁₅	----	----	1980	----	----	----
N(1990)	F ₁₇	**	2005(350)	1980	----	----	2011
N(2000)	F ₁₅	**	1882(95)	1995	1814(176)	----	----
----	P ₁₃	----	----	2030	----	----	----
----	S ₁₁	----	----	2030	----	----	----
----	D ₁₃	----	----	2055	----	----	----
----	S ₁₁	----	----	2070	----	----	----
N(2080)	D ₁₃	**	2081(265)	1960	----	----	----
----	D ₁₅	----	----	2080	----	----	----
N(2090)	S ₁₁	*	1880(95)	1945	----	----	----
----	D ₁₃	----	----	2095	----	----	----
N(2100)	P ₁₁	*	2050(200)	2065	----	----	----
----	S ₁₁	----	----	2145	----	----	----
----	D ₁₃	----	----	2165	----	----	----
----	D ₁₃	----	----	2180	----	----	----
----	D ₁₅	----	----	2180	----	----	----
N(2190)	G ₁₇	****	2140(390)	2090	2131(476)	2192(726)	2075
----	S ₁₁	----	----	2195	----	----	----
N(2200)	D ₁₅	**	2228(310)	2095	----	----	----
----	G ₁₇	----	----	2205	----	----	----
----	P ₁₁	----	----	2210	----	----	----
N(2220)	H ₁₉	****	2205(365)	2345	2258(334)	2270(366)	2327
----	D ₁₅	----	----	2235	----	----	----
N(2250)	G ₁₉	****	2268(300)	2215	2291(772)	2376(924)	2234
----	G ₁₇	----	----	2255	----	----	----
----	D ₁₅	----	----	2260	----	----	----
Σ = 19			Σ = 18	Σ = 40	Σ = 13	Σ = 10	Σ = 10

Table 2. Parameters of the Δ – resonances.

PDG (2004)	L_{3,2J}	Status	KA84 (1984)	(³P₀)model (1994)	SM95 (1995)	FA02 (2004)	Skyrme (1985)
$\Delta(1232)$	P ₃₃	****	1233(116)	1230	1233(114)	1233(118)	1424
$\Delta(1600)$	P ₃₃	***	1522(222)	1795	[1675-i193]	----	1435
$\Delta(1620)$	S ₃₁	****	1610(139)	1555	1617(108)	1614(141)	1478
$\Delta(1700)$	D ₃₃	****	1680(230)	1620	1680(272)	1688(365)	1737
$\Delta(1750)$	P ₃₁	*	----	1835	----	----	----
$\Delta(1900)$	S ₃₁	**	1908(140)	2035	----	----	----
$\Delta(1905)$	F ₃₅	****	1905(260)	1910	1850(294)	1856(334)	1931
$\Delta(1910)$	P ₃₁	****	1888(280)	1875	2152(760)	2333(1128)	1982
$\Delta(1920)$	P ₃₃	***	1868(220)	1915	----	----	1946
$\Delta(1930)$	D ₃₅	***	1901(195)	2155	2056(590)	2046(402)	1730
$\Delta(1940)$	D ₃₃	*	----	2080	----	----	----
$\Delta(1950)$	F ₃₇	****	1923(224)	1940	1921(232)	1923(278)	1816
----	P ₃₃	----	----	1985	----	----	----
$\Delta(2000)$	F ₃₅	**	----	1990	----	----	----
----	D ₃₃	----	----	2145	----	----	----
----	D ₃₅	----	----	2165	----	----	----
$\Delta(2150)$	S ₃₁	*	----	2140	----	----	----
$\Delta(2200)$	G ₃₇	*	2215(400)	2230	----	----	2162
----	G ₃₇	----	----	2295	----	----	----
----	D ₃₅	----	----	2325	----	----	----
$\Delta(2300)$	H ₃₉	**	2217(300)	2420	----	----	2407
$\Delta(2350)$	D ₃₅	*	2305(300)	2265	----	----	----
$\Delta(2390)$	F ₃₇	*	2425(300)	2370	----	----	----
$\Delta(2400)$	G ₃₉	**	2468(480)	2295	----	----	2083
$\Delta(2420)$	H _{3,11}	****	2416(340)	2450	----	----	2327
----	F ₃₇	----	----	2460	----	----	----
----	H ₃₉	----	----	2505	----	----	----
$\Sigma = 20$			$\Sigma = 16$	$\Sigma = 27$	$\Sigma = 8$	$\Sigma = 7$	$\Sigma = 13$

Table 2a. Comparison of the PWA results and model predictions
for the N^* - and Δ - resonances numbers.

References	N^* -number	Δ -number
RPP(1980); C.Bricman et al., Rev.Mod.Phys.52, 175(1980).	26	19
RPP(2006); W.-M.Yao et al., Journ.Phys. G33, 1(2006).	21	22
PWA KH80; G. Hoehler, Physics Data. No12-1,Karlsruhe,(1979).	21	18
PWA KA84; G. Hoehler et al., π N-Newsletters 9,1(1993).	18	16
PWA CMB; R.E. Cutcosky, et al., Phys.Rev.D20, 2839(1979).	16	13
Anal. T.P.Vrana; T.P.Vrana et al., nucl-th/9910012.	14	13
PWA SM95; R.A. Arndt et al., Phys.Rev.C52}, 2120(1995).	13	8
PWA FA02; R.A. Arndt et al., Phys.Rev.C69, 035213(2004).	10	7
PWA SP06; R.A. Arndt, et al., nucl-th/0605082.	13	9
Mod. S.Capstick; S.Capstick et al., Phys.Rev.D49}, 4570(1994).	40	27
Mod. U.Loring; U.Loring et al., hep-ph/0103289.	99	82
Skyrme model; M.P.Mattis et al., Phys.Rev.D31, 2833(1985).	10	13
Mod. J.Vijande; J.Vijande et al., hep-ph/0312165.	19	21

At the next picture the prediction of the harmonic oscillator $SU(6) \times O(3)$ model is shown (R.H.Dalitz, L.J.Reinders - 1977).

It can be seen that this model predictions are far from all PWAs results.

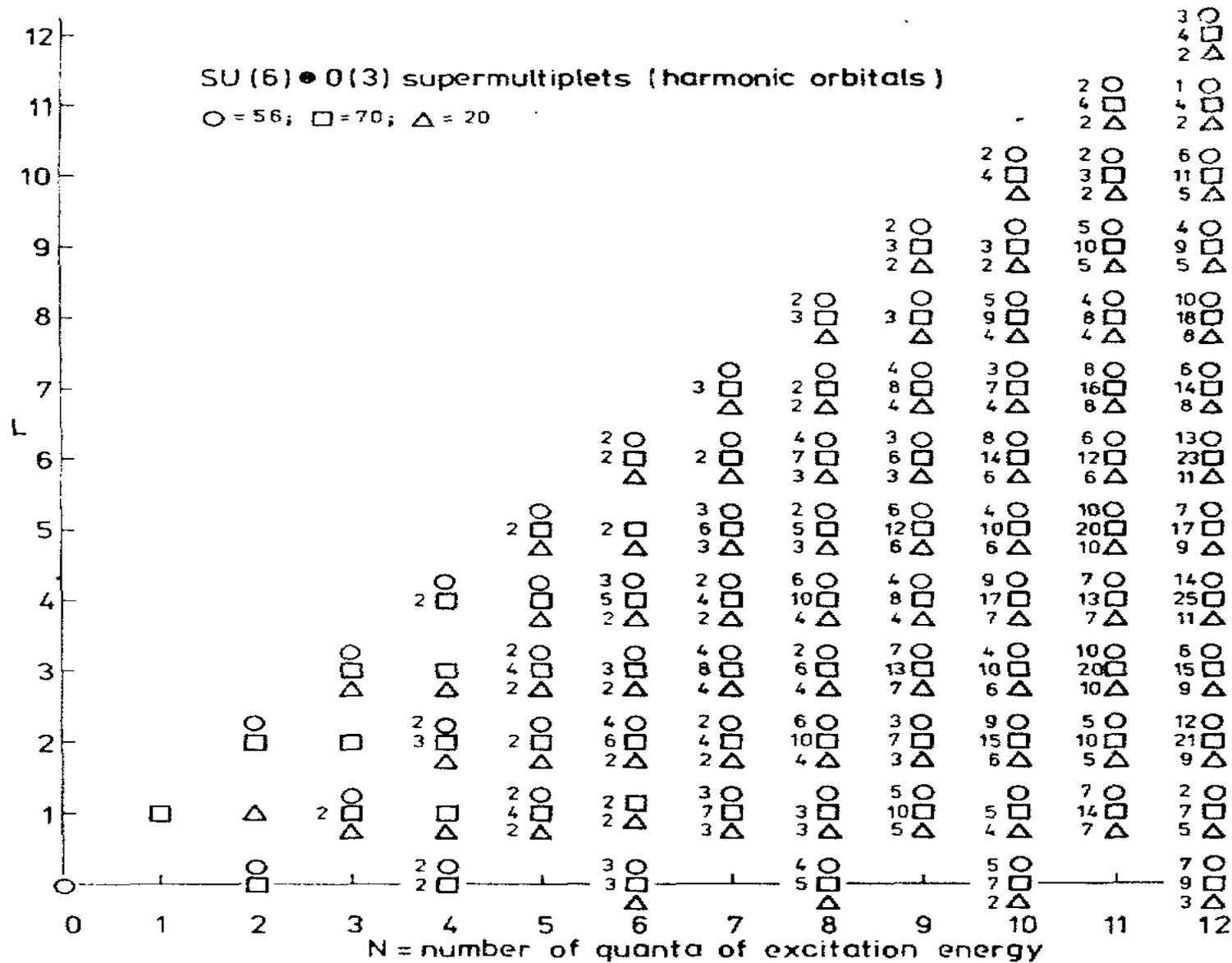


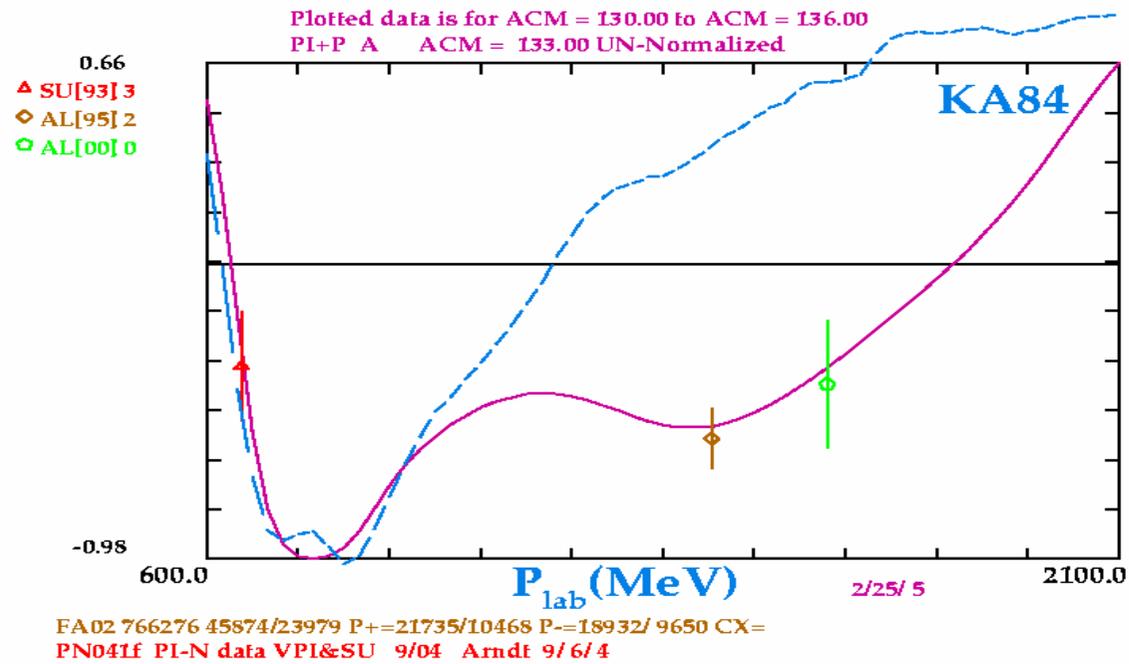
Fig. 1. The multiplicities of the 56, 70 and 20 supermultiplets are shown as function of the degree of excitation N and the orbital angular momentum L , for $L \leq 12$ and $N \leq 12$.

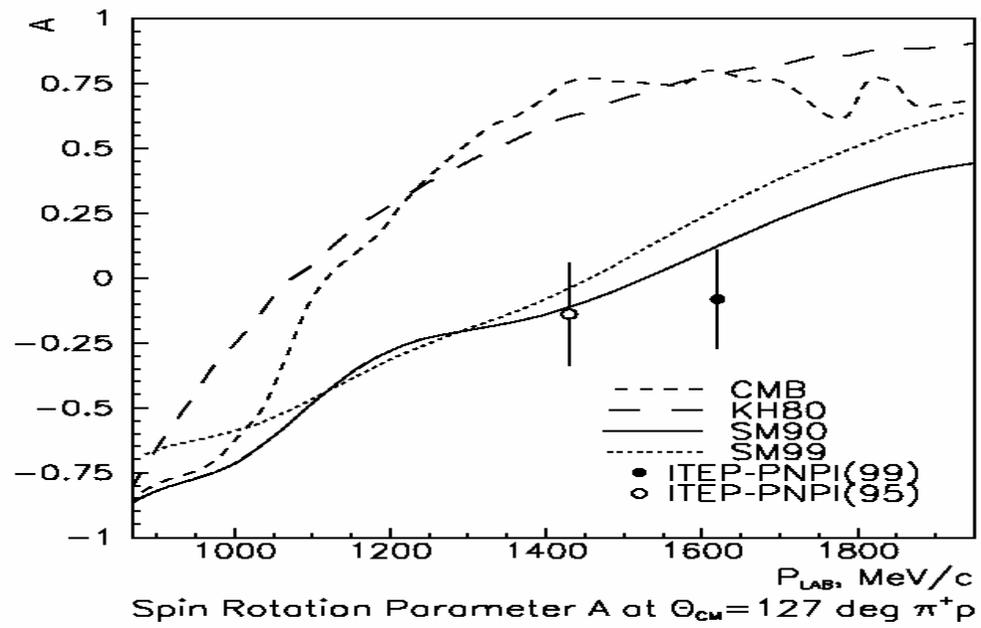
3.Results of PNPI-ITEP collaboration measurements.

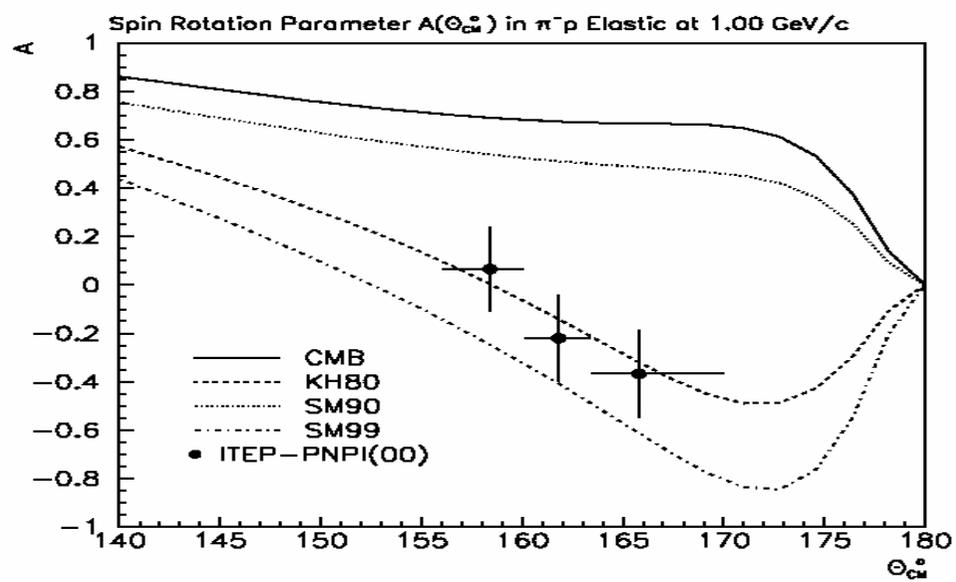
Earlier, the authors of the global PWAs supposed that the appearance of new experimental data would allow reliable determination of those Baryon resonances which had low status (**) and (*) in the RPP.

However, the series of the PNPI-ITEP Collaboration experiments that was aimed at resolving the discrete ambiguities in the PWA procedure and that was supported by the Russian Foundation for Basic Research (projects from no. 99-02-16635 before no. 04-02-16335) unexpectedly led to the opposite result. Namely , they confirmed the predictions of the PWA of the VPI-GWU group for the spin rotation parameters A and R. This analysis did not reveal the baryon resonances with low confidence status (**) and (*) that were presented in the RPP tables (see Tables 1 and 2 in this submission).

At next pictures the results of PNPI-ITEP collaboration measurements are compared with PWAs predictions.







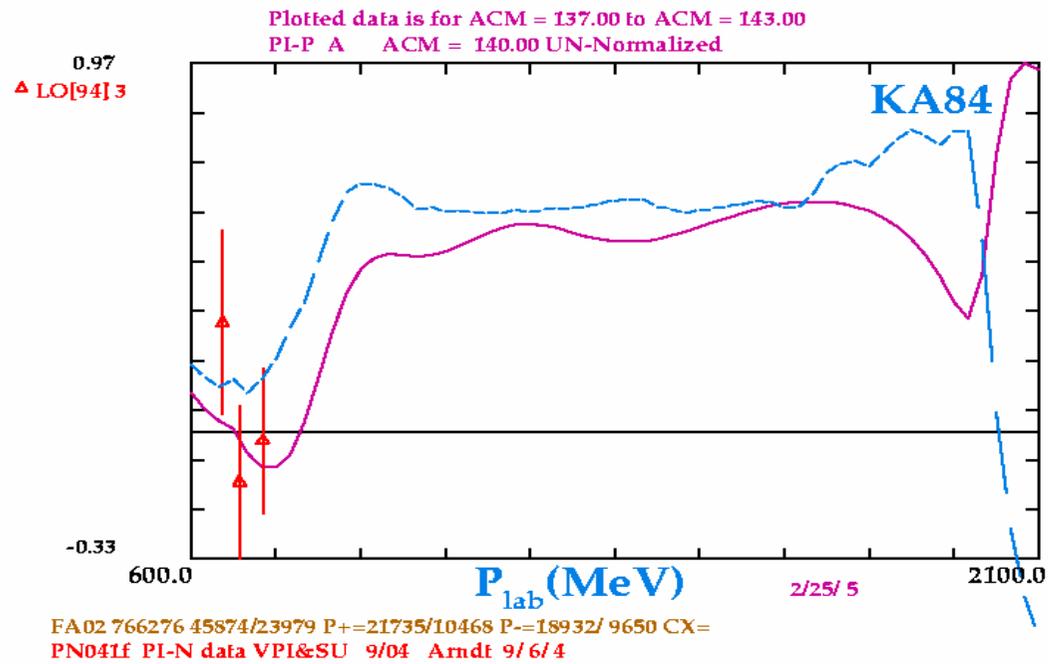
4. Program of the spin rotation parameters A and R measurements

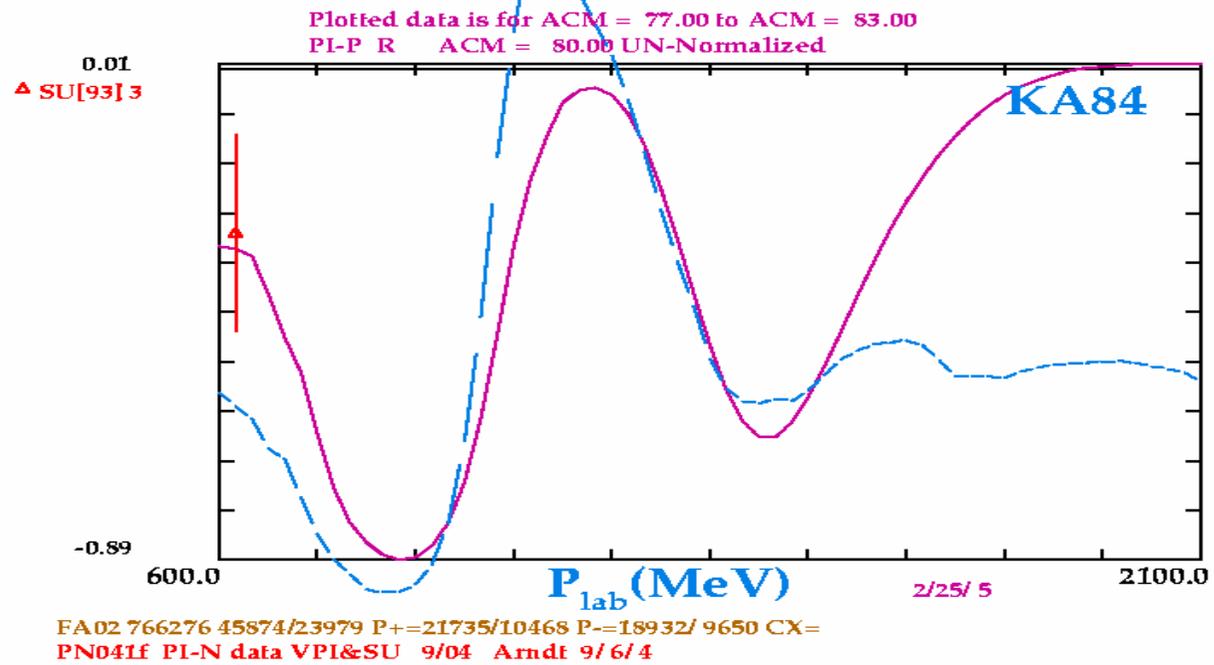


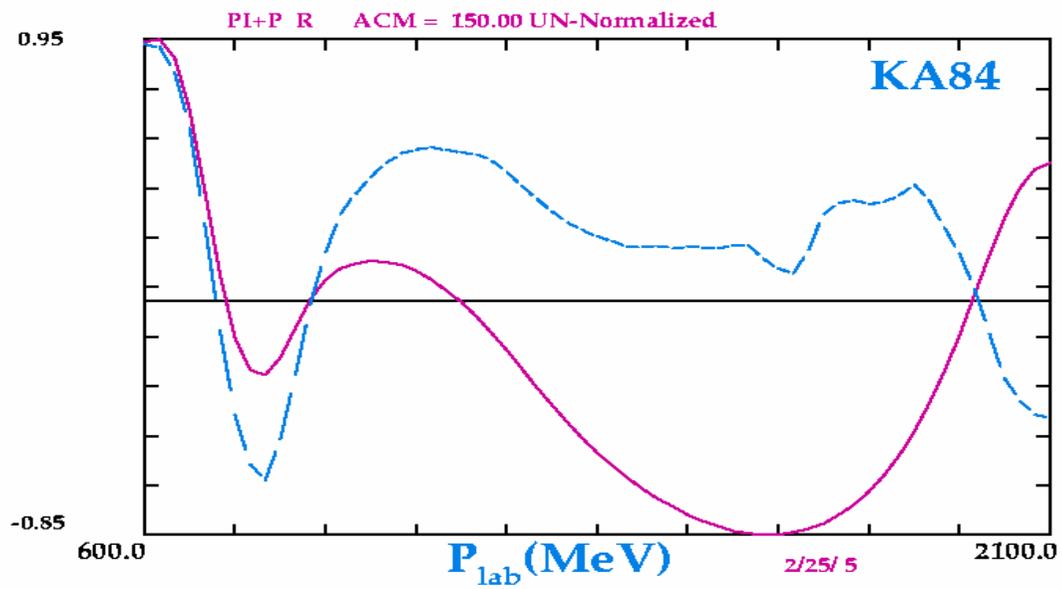
At the moment, it has become clear that the program of the PNPI-ITEP Collaboration aimed at resolving the discrete ambiguities of the available PWAs is completely justified and it should be continued up to the complete resolution of all presumably existing discrete ambiguities.

The specific feature of measurements of the spin rotation parameters is that it is not necessary to make measurements in the full energy and angle ranges. It is enough to measure these parameters **in some limited intervals of kinematics variables** – that can be determined beforehand on the base of existing PWAs.

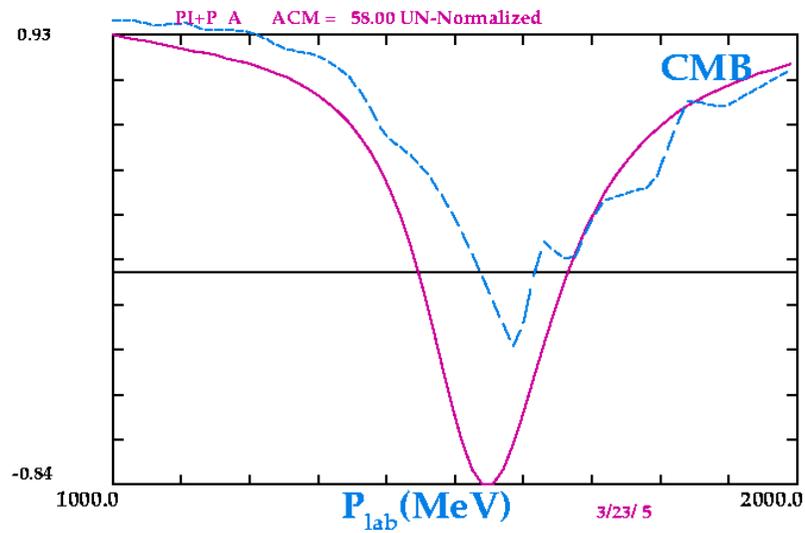
It is clear from the next pictures.



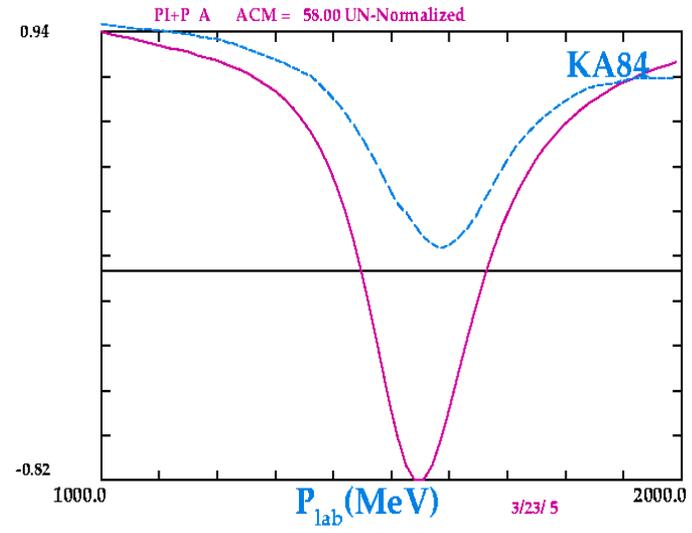




FA02 766276 45874/23979 P+=21735/10468 P-=18932/ 9650 CX=
 PN041f PI-N data VPI&SU 9/04 Arndt 9/ 6/ 4



FA02 766276 45874/23979 P+=21735/10468 P-=18932/ 9650 CX=
 PN041f PI-N data VPI&SU 9/04 Arndt 9/6/4



FA02 766276 45874/23979 P+=21735/10468 P-=18932/ 9650 CX=
 PN041f PI-N data VPI&SU 9/04 Arndt 9/6/4

Program of the spin rotation parameters A and R measurements

In Tables 3 and 4 we present these limited intervals of kinematic variables for the second resonance region of πN elastic scattering, which cover masses of baryon resonances from 1400 to 2000 MeV.

In column 2 and 3 those intervals of lab. pion momentum and c.m.s. scattering angle are indicated, in which the existence of discrete ambiguities is mostly probable and, hence, measurements of the spin rotation parameters in πp elastic scattering are needed on the first turn. Expected counting rates can be estimated using values of c.m.s. differential cross sections given in column 4. A statistical precision at a level of ΔA (ΔR) ≈ 0.1 is enough to distinguish different PWA solutions.

Table 3: Elastic $\pi^+p-\pi^+p$ scattering.
 (Regions with presumed existence of discrete ambiguities.)

Number	Momentum region (MeV/c)	Angle region c.m.s.(deg.)	Diff. cross section (mb/sr)
1	700 – 900	90 - 110	0.03 - 0.18
2	800 – 1000	155 – 175	0.08 – 0.60
3	800 – 1200	80 – 100	0.13 – 0.27
4	1600 – 1900	50 – 70	0.08 – 0.30
5	1800 – 2100	130 - 150	0.03 – 0.13

Table 4: Elastic $\pi^-p-\pi^-p$ scattering.
 (Regions with presumed existence of discrete ambiguities.)

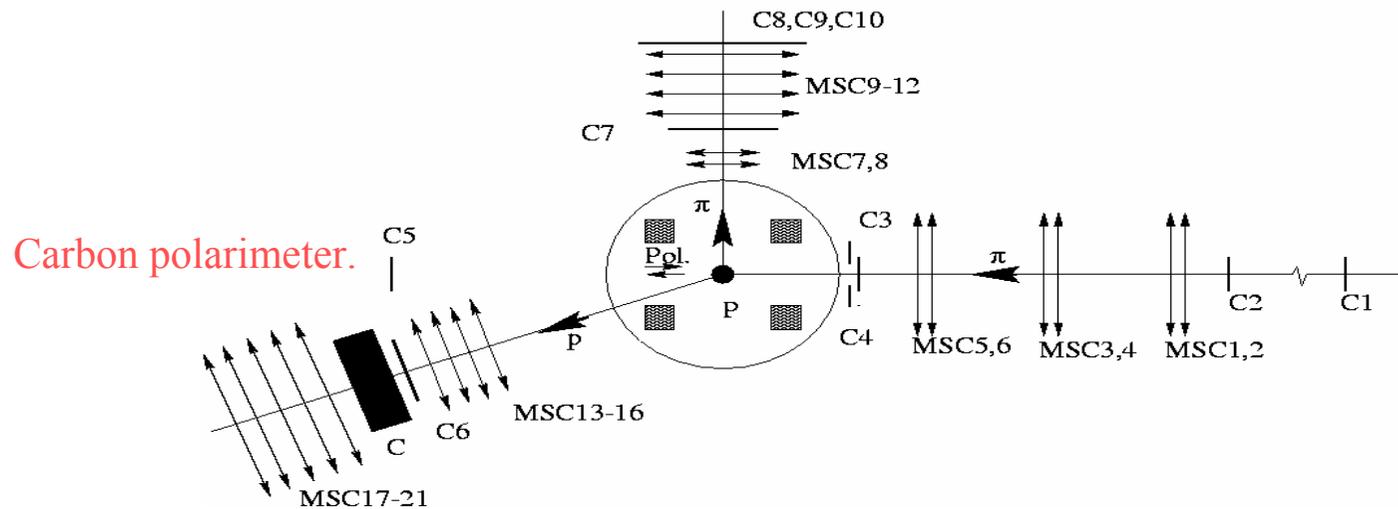
Number	Momentum region (MeV/c)	Angle region c.m.s.(deg.)	Diff. cross section (mb/sr)
1	600 – 800	60 - 80	0.06 - 0.20
2	600 – 800	100 – 120	1.0 – 1.4
3	1200 – 1400	150 – 170	0.30 – 0.53
4	1200 – 1500	60 – 80	0.05 – 0.23
5	1200 - 1500	90 - 110	0.25 – 0.40
6	1800 – 2100	140 - 150	0.002 – 0.010
7	2000 - 2100	130 - 150	0.001 – 0.003

5. Experimental setup.

Main elements of the experimental setup for the spin rotation parameters A and R measurements.

There are:

1. Polarized target.
2. Carbon polarimeter.
3. Track detectors (MSC).
4. Scintillation counters (C).



6. Conclusion.

At the next possible stage, it is proposed to make similar measurements also in the third region of πN elastic scattering (masses of baryon resonances are around 3 GeV, corresponding $T_\pi > 2.2$ GeV).

Only one PWA KA84 covers this region. As it was shown [6] by measurements of the spin rotation parameter A made by the PNPI-ITEP collaboration in the second resonance region, in the analysis KA84 an incorrect solution has been chosen in the range $T_\pi = 1.3\text{--}1.6$ GeV; hence, the validity of this analysis at $T_\pi > 2.2$ GeV also needs to be checked experimentally.



The experiment planning by the zero trajectory consideration.

{ Barrelet method employment. }

The basic idea of the Barrelet methods is to represent the transverse amplitudes F_{θ} at fixed energy by the following ansatz, which exhibits the zeros in the complex $z = \cos\theta_{cm}$ - plane:

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$$F(\theta; z) = F(1) \times \prod_{i=1}^N [(z - z_{\theta_i}) / (1 - z_{\theta_i}^*)] \times R(\theta; z); \quad R(\theta; 1) = 1.$$

as functions of a variable ω , which is connected with z by a conformal mapping $e^{i\theta} = z \pm (z^2 - 1)^{1/2}$. When θ is real, it corresponds to the center-of-mass scattering angle. This mapping has the property, that a physical value of z (i.e. z real and $|z| < 1$) is mapped onto two points in the ω -plane, which lies on the upper and lower halves of the unit circle, respectively. Here ω and ω^{-1} belong to the same value of z .

Transverse amplitudes have the advantage, that their modulus can be determined from $d\sigma/d\Omega$ and P data alone $|F_{\alpha}| = d\sigma/d\Omega \times (1 - P)$.

This equation shows that the zeros of the amplitude can be derived from the zeros of $d\sigma/d\Omega$ and P data but, unfortunately, there is a 2^{2N} fold ambiguity because for each pair of zeros z_i and z_i^* (or ω_i and $1/\omega_i^*$) one has the choice whether z_i or z_i^* belongs to the amplitude F .

The spin rotation parameters A and R measurements can help in such choice.

The positions of the zeros of F_{α} depends of course on the incident pion beam momentum. This allows one to locate problems of the unknown PWA ambiguities **simply by looking at the zero trajectories on the ω - planes which are near the physical region.**

